EXPERIMENTERS CORNER

DESIGNING CLASS "A" TRANSISTOR OUTPUT STAGES

C. R. BOGGIS, M.A.P.A.E.

THE purpose of this article is to show that it is possible to design an output stage operating in the class "A" mode, with very little involved mathematics. The design procedure is based on several "rules of thumb" and the assumption that the losses are negligible.

A power amplifier designed by this method will prove to be a viable proposition, and gives the added satisfaction of being able to say "I designed and built it myself". For simplicity of design the input to the amplifier is transformer coupled, see Fig. 1.

First we decide on the output power required and the supply voltage that is available. We then choose a transistor capable of meeting the specification. In this example, the required power is 2 watts and the power supply is to be a fully-charged car battery, the voltage of which will be about 14·5 volts.

A transistor which will more than "fit the bill" is type OC35, which is, incidentally, readily available on the surplus market. Ignoring any losses, the power required (P_o) is equal to the peak collector current (I_c) times the peak collector voltage (V_c), each divided by the square root of 2 to obtain r.m.s. values.

The peak collector current can be determined thus:

$$P_o = \frac{V_c}{\sqrt{2}} \times \frac{I_c}{\sqrt{2}} \qquad \therefore I_c = P_o(\sqrt{2}) \times \frac{\sqrt{2}}{V_c}$$

Substituting our requirements this becomes:

$$= 2\sqrt{2} \times \frac{\sqrt{2}}{14{\cdot}5} = 278\text{mA, or approx. 300mA.}$$

In class "A", the d.c. collector current and the peak collector current are similar, and can be considered equal. Thus the collector voltage and current are 14·5 volts and 0·3 amps respectively. The voltage drop across R_e is usually around 0·6 volts in power output stages. This value is calculated from: $R_e = \frac{V}{I_e}$ where V equals 0·6 volts, and I_e is considered equal to I_c, which is equal to 0·3 amps. Thus here R_e=2 ohms.

The voltage from base to earth is equal to the base-to-emitter voltage (V_{be}) of the transistor (normally 0·6 volts in silicon, 0·4 volts in germanium transistors) plus the voltage drop across R_e, in this case 0·6V. The voltage across R2 is therefore 1V. By "rule of thumb" R2 is made equal to R_e times 10, or 20 ohms (use preferred value 22 ohms). Thus the current through R2 is equal to the voltage across R2 divided by R2, which equals in this example 45mA.

The current through R1 can be considered equal, since the base current is very small in comparison with the bleed current through resistors R1 and R2.

Thus R1$=\frac{14{\cdot}5-1}{45\text{mA}}=320$ ohms (use 330 ohms). (The voltage drop across T1 can be ignored, the d.c. resistance being very small.)

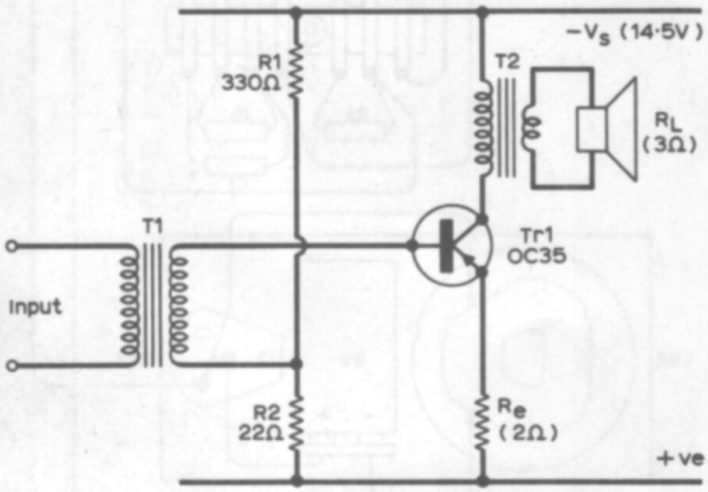

Fig. 1: The circuit referred to in the text.

The output transformer requirements are calculated from the a.c. voltages and currents in the circuit. The peak collector voltage swing that can be utilised before "clipping" occurs is approximately 90% of the supply voltage, or 13 volts in this example.

The peak collector current swing available is, as previously stated, 300mA. The collector load should thus be 13 volts divided by 300mA or approx. 43 ohms in this case. The transformer should match this impedance to the actual load impedance used. A 3 ohm loudspeaker is to be the load here, thus the impedance ratio should be 43:3 ohms or the turns/voltage ratio should be $\sqrt{(43:3)}$ or 3·8:1.

The total input power that is required to drive the stage to full output is the voltage needed across T1 secondary times the current. This current is equal to the base current required. This is determined from the transistor characteristics, being the value of peak collector current divided by the β value for the transistor at that current. Here, β is equal to the range 25-75 for an OC35. Choosing the mean, 50, and from previously calculated collector current 300mA, drive signal required is 0·3A divided by 50, which equals 6mA peak, or 4·2mA r.m.s.

The peak input a.c. voltage is nearly equal to the sum of the base-emitter voltage, plus the voltage across R_e, plus the peak a.c. voltage across R2 (6mA × 22 ohms).

Thus, in this case, the drive voltage required is equal to 1·132V peak (0·4V+0·6V+0·132V) or 0·8 volts r.m.s. The total a.c. power required is thus 0·8 volts times 4·2mA, or 3·4mW. The input impedance is 0·8 volts divided by 4·2mA, that is about 200 ohms. T1 should be designed to match this impedance to the optimum load for the preceding stage. This can be designed along the same lines as the power amplifier discussed in this article. ■

EXPERIMENTERS CORNER

DESIGNING CLASS "A" TRANSISTOR AMPLIFIERS

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DESIGNING basic transistor amplifier stages can be made very simple by following a few "rules of thumb", so enabling the experimenter with but a modicum of theoretical knowledge to tailor established circuits to his own needs. This article, which can be read in conjunction with last month's "Experimenters Corner", describes how to work out the component values for germanium or silicon amplifiers and couple them to other stages without upsetting their operation.

Germanium Amplifiers

If a single amplifier stage as shown in Fig. 1 is designed as follows it will be able to function over the temperature range of 20 to 50° Centigrade. In the worked example, a general-purpose small signal transistor is used (Mullard type OC71, or similar).

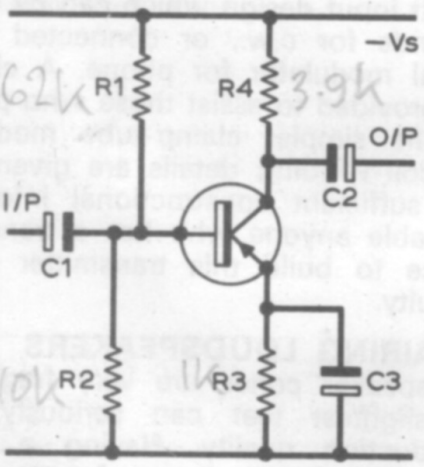


Fig. 1: A straightforward amplifier stage suitable for a germanium transistor.

First the supply voltage is chosen. Here we select 9 volts, this being readily available from standard batteries. We then decide on a value of collector current. For a very small input and low noise this should be around 100-200 microamperes, but for large inputs the current could be anything up to about 100 milliamps. As a general rule a current of 1mA is desirable, and it is around this figure that the stage designed here is evolved.

Having decided on the collector current, the first rule may be applied. This states that the emitter resistor should drop approximately 1 volt. Therefore in our example, R3 will be equal to $\frac{1 \text{ volt}}{1\text{mA}}$, since the emitter current can be considered equal to the collector current for this purpose, which suggests a resistor value of 1000 ohms.

The next rule states that for good stability, the collector voltage should be equal to half of the result of subtracting the emitter voltage from the supply voltage. Here the collector voltage should be $\frac{9-1 \text{ volts}}{2}$ or 4 volts.

With a collector current of 1mA, R4 should be $\frac{4 \text{ volts}}{1\text{mA}} = 4000$ ohms, the nearest preferred value being 3·9kΩ.

Using yet another rule of thumb, R2 should be 10 times R3, which yields a value of $10 \times 1\text{k}\Omega$, or 10kΩ in this case.

The base voltage is determined by the V_{be} for the transistor plus the emitter voltage. For a germanium transistor, $V_{be} = 0{\cdot}2$ volts approx., so the base voltage required is 1·2 volts. The current through R1 is the same as the current through R2, since the base current, being very small, can be ignored. This current equals $\frac{1{\cdot}2 \text{ volts}}{10\text{k}\Omega}$, which is 120 microamps. Thus R1 should drop 9−1·2 or 7·8 volts at 120 microamps. R1 therefore equals $\frac{7{\cdot}8 \text{ volts}}{120\mu\text{A}}$, which is 65kΩ (use a 62kΩ preferred value).

The values of C1 and C2 hardly need calculating. Suffice to say that their reactance should be negligible at the lowest frequency to be amplified. An ideal value for each is 10μF. The working voltage is determined by the collector voltage of the stage and the base voltage in the following stage—usually a 6 volt capacitor will be suitable. Note the polarity of these two capacitors.

C3 should also be chosen such that its reactance is small at the lowest frequency. Here a value of 50μF will be ample, but again, note the polarity.

Silicon Amplifiers

Using silicon transistors it is possible to obtain adequate temperature stability with a simplified circuit as shown in Fig. 2. The design procedure is even simpler

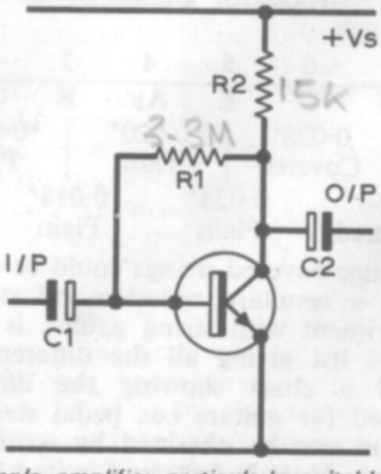
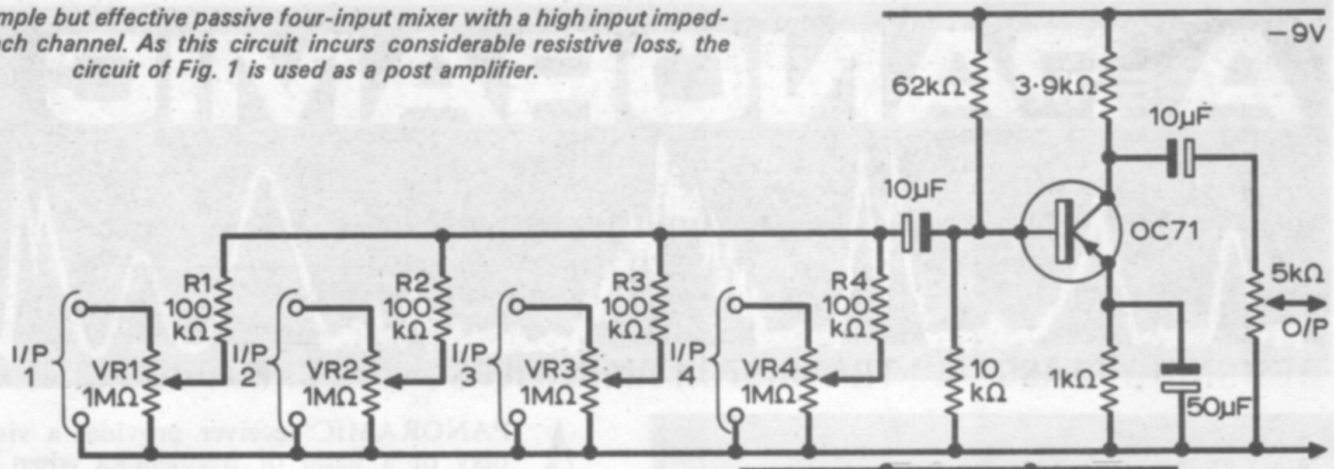


Fig. 2: A simple amplifier particularly suitable for a silicon transistor.

Fig. 3: A simple but effective passive four-input mixer with a high input impedance to each channel. As this circuit incurs considerable resistive loss, the circuit of Fig. 1 is used as a post amplifier.



with this circuit, the number of components being so few.

First, choose the supply voltage; say 6 volts. The collector current is picked next. Here a value of 200µA is used, as we are designing an input stage to be fed from a microphone, and low noise is most important. The transistor chosen is a Mullard BC109 (or similar).

As in the previous example using a germanium transistor, the collector voltage should be approximately half the supply voltage minus the emitter voltage. As the emitter voltage is zero, the collector voltage should be 3V. R2 will therefore be equal to $\frac{3 \text{ volts}}{200\mu A}=15k\Omega$.

R1 is arranged to drop the collector voltage down to the level required for the base of the transistor. The base voltage needed here is equal to the V_{be} for the transistor, which is about 0·4 volts for silicon.

The base current required is calculated from the collector current divided by h_{fe} or beta for the transistor at that collector current. For the BC109, h_{fe} at I_c= 200µA is typically 300, so the required base current is $\frac{200\mu A}{300}$, which is 0·6µA. R1 is therefore equal to $\frac{3-0{\cdot}4 \text{ volts}}{0{\cdot}6\mu A}$, which is 4MΩ. Allowing for somewhat lower h_{fe} values that may occur in production spreads R1 should be chosen as 2·7-3·3MΩ.

Using the Circuitry

The circuit designed in Fig. 1 could be utilised in many ways. It could be used to amplify the signal from the detector of a tuner up to sufficient level to drive an earphone, in which case R4 should be replaced by a headset with a d.c. resistance of 4000 ohms. Alternatively, R4 may be left in circuit and driver and output stages added to drive a loudspeaker.

Another application could be as an audio mixer for several inputs, and the circuit in Fig. 3 shows such an arrangement. Resistors R1-R4 are included to reduce interaction between each of the mixer volume controls. The volume control at the output is the master volume control, and is effective over all inputs. By inverting the supply rail polarity, the circuit in Fig. 2 could be substituted for the OC71 amplifier stage.

High Input Impedance

Where a high input impedance is required such as for amplification of a gramophone pick-up output, an emitter follower can be used in front of the circuit in Fig. 2. This additional amplifier is shown in Fig. 4, and this will give an input impedance of approximately 2MΩ. This is because the input impedance of the

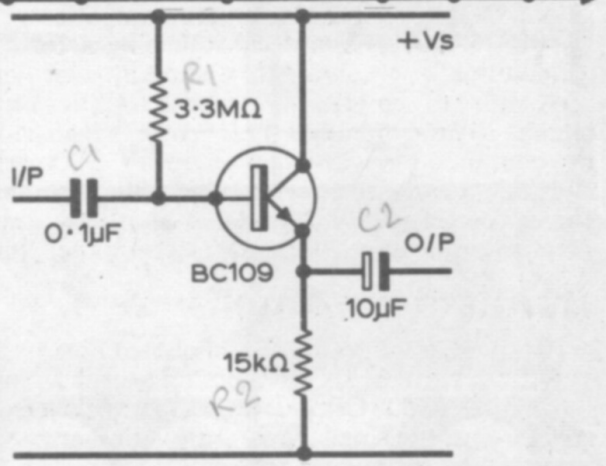


Fig. 4: An emitter-follower which exhibits a very high input impedance and a low output impedance. Its voltage gain is fractionally less than 1.

transistor is almost equal to the beta or h_{fe} times R_e.

Input Z=300×15kΩ=4·5MΩ.

This is shunted by R1, which is 3·3MΩ, so the input impedance=$\frac{3{\cdot}3\times4{\cdot}5}{3{\cdot}3+4{\cdot}5}M\Omega=2M\Omega$. ■

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